b. Final Progress Report

(1) n/a

(2) Table of Contents

(3) n/a

(4) The problem studied with support from ARO Grant DAAH-04-96-01-0187 was the interaction of light with randomly rough surfaces, with an emphasis on multiple-scattering phenomena occurring in such interactions. These include enhanced backscattering, enhanced transmission, satellite peaks, spectral changes, intensity correlation functions, and nonlinear phenomena.

(5) Summary of the most important results
SEE ATTACHED

(6) List of all publications and technical reports
SEE ATTACHED

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Mr. I. V. Novikov and Mr. A. V. Shchegrov earned the Ph. D. degree in physics while employed on this project.

(8) n/a

(9) n/a

(10) n/a

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REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
January 17, 2000

3. REPORT TYPE AND DATES COVERED
Final Prog. Report 6/1/96-5/31/99

4. TITLE AND SUBTITLE
Optical Interactions at Rough Surfaces

5. FUNDING NUMBERS
DAAH04-96-1-0187

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
ARO 35549.11-PH

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12 b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The research carried out with support from Army Research Office Grant DAAH-04-96-01-0187 was devoted to several areas of the scattering of light from, and its transmission through, randomly rough surfaces. These include changes in the spectrum of light due to its scattering from a randomly rough surface; the design of random surfaces that scatter light uniformly within a specified range of scattering angles, and produce no scattering outside this range; multiple-scattering effects in the second harmonic generation of light scattered from a random metal surface; the coexistence of ballistic wave propagation, diffusive wave transport, and wave localization in random waveguides; calculations of the elements of the Stokes matrix in conical scattering; the scattering of surface electromagnetic waves by surface defects; and new features in the angular intensity correlation functions of light scattered from random media.

14. SUBJECT TERMS multiple scattering; random surfaces; second harmonic generation; band-limited uniform diffusers; intensity correlations; conical scattering; enhanced backscattering.

15. NUMBER IF PAGES
12

16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Enclosure 1

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

Summary of the most important results

During the period June 1, 1996 - May 31, 1999 a total of 32 papers were published that acknowledged support from Army Research Office Grant DAAH 04-96-1-0187. They are listed in the attached bibliography. In this section we describe some of the highlights of the work reported in these papers.

1. Surface-Enhanced Spectral Shifts of Light Scattered from Random Surfaces

The spectrum of light in the far-field emitted by a quasihomogeneous source can be red-shifted or blue-shifted with respect to that of the source, if the degree of spectral coherence of the latter is appropriately chosen (E. Wolf, Nature **326**, 363 (1987); Phys. Rev. Lett. **58**, 2646 (1987); Optics Commun. **62**, 12 (1987)). A recent theoretical investigation of the spectral shifts of light scattered from the one-dimensional random surface of a dielectric film deposited on the planar surface of a perfect conductor showed that they could be quite large for scattering angles in the vicinity of the angles at which satellite peaks occur in the angular dependence of the intensity of the incoherent component of the light scattered from this system, when it is illuminated by monochromatic light (T. A. Leskova, *et al.* Phys. Rev. Lett. **79**, 1010 (1997)). These satellite peaks are a consequence of the several waveguide modes supported by the scattering system (J. A. Sánchez-Gil, *et al.* Phys. Rev. B**50**, 15353 (1994)). This result prompted a search for other structures bounded by a random surface that could produce large spectral shifts of light scattered from them. Such a structure is a semi-infinite metal with a one-dimensional randomly rough surface that is separated by a sub-wavelength air gap from the planar base of a prism through which the metal surface is illuminated – the Otto attenuated total reflection (ATR) configuration (A. Otto, Z. Physik, **216**, 398 (1968)). The angular dependence of the intensity of p-polarized light of frequency ω_0 scattered from this system displays sharp intense peaks at scattering angles at which the optimal radiation of the surface plasmon polaritons of frequency ω_0 supported by the air-metal interface occurs. P-polarized polychromatic light of central frequency ω_0 incident normally on the Otto ATR configuration was found to be blue-shifted when scattered into the retroreflection direction(1)[1]. However, for scattering angles in the vicinity of the angles at which the optimal radiation of surface plasmon polaritons occurs, $\pm 34.7°$ for the system studied, namely a fused silica prism and a silver substrate, the spectrum of the scattered light was blue-shifted when the scattering angles was smaller in amplitude than these angles, but was red-shifted when it was larger in magnitude than these angles. The magnitudes of the latter shifts were quite large: the relative shift $(\omega_m(\theta_s)-\omega_0)/\omega_0$, where $\omega_m(\theta_s)$ is the position of the maximum of the spectrum of the scattered light as a function of the scattering angle θ_s, could reach a value of 0.025, when the linewidth of the incident light $\Delta\omega$ was $\Delta\omega/\omega_0 = 0.05$. Shifts of this magnitude are large enough to be measured.

[1] The references are to articles listed in the attached bibliography.

2. Design of Band-Limited Uniform Diffusers

For many practical applications it is desirable to have optical diffusers whose light scattering properties can be controlled. In particular, a nonabsorbing diffuser that scatters light uniformly within a range of scattering angles, and produces no scattering outside this range, would have applications, for example, to projection systems, where it is important to produce even illumination without wasting light. Such an optical element is called a *band limited uniform diffuser.*

Two approaches to generating numerically one-dimensional random surfaces that act as band-limited uniform diffusers have been proposed recently[2,3]. On the basis of the geometrical optics limit of the Kirchhoff approximation it was shown that one-dimensional random surfaces with this property are characterized by a probability density function (pdf) of slopes that is constant within a prescribed range of slopes and vanishes outside it. In the first approach the surface was generated by centering ridges of trapezoidal cross-section on equally spaced lines of a planar substrate with weights that were obtained from a pdf that is directly related to the desired pdf of slopes of the surface. In the second approach the derivative of the random surface was obtained from the stationary solution of the problem of tracking the coordinate of a particle that executes a one-dimensional random walk between two perfectly reflecting walls, in which the probabilities of the particle jumping to the right or to the left, or staying at its site, at the i^{th} time step, are related to the desired pdf of slopes of the surface. The surface itself was then obtained by a numerical integration. Rigorous computer simulations of the scattering of s-polarized light from perfectly conducting surfaces generated by both of these approaches showed that the resulting scattered intensity is indeed constant within the prescribed range of scattering angles which, at normal incidence, can be as small as $-1° < \theta_s < 1°$, and is zero outside this range.

The fabrication of one-dimensional metallic surfaces that act as band-limited uniform diffusers has recently been carried out[3]. Experimental results for the angular dependence of the intensity of the light scattered from them show that these surfaces give rise to a scattered intensity that is nonzero only within a prescribed angular region, but they do not yet give rise to a constant intensity within this region. It is believed that this feature can be corrected by increasing the length of the fabricated surface.

3. Multiple-Scattering Effects in the Second Harmonic Generation of Light Scattered from a Random Metal Surface

For randomly rough metallic surfaces, the multiple scattering that gives rise to enhanced backscattering may contain processes that involve the excitation of surface plasmon polaritons (A. R. McGurn *et al.*, Phys. Rev. **B31**, 4866 (1985); A. A. Maradudin and E. R. Méndez, Appl. Opt. **32**, 3335 (1993)) or the multiple scattering of volume waves (A. A. Maradudin, *et al.*, Opt. Lett. **14**, 151 (1989)). The former is the main mechanism responsible for enhanced backscattering from weakly rough surfaces, and the latter appears to be the dominant mechanism in the case of strongly rough surfaces.

The main ideas associated with this effect have also been applied to multiple-scattering phenomena occurring in the scattering of light from random nonlinear surfaces. In particular, it has been suggested that the second harmonic generation of light incoherently scattered by a randomly rough metal surface not only presents interesting features in the backscattering direction, but also in the direction normal to the surface (A. R. McGurn *et al.*, Phys. Rev. B**44**, 11441 (1991)). These predictions were based on a perturbative theory that applies only to weakly rough surfaces. Not surprisingly, surface plasmon polaritons play a prominent role in the formation of the predicted features, and it is known that the backscattering effects are due to the nonlinear excitation of surface plasmon polaritons at the second harmonic frequency (2ω). Subsequent work[4] has shown that depending on the values of the phenomenological constants that describe the nonlinear interactions at the metal surface, it is possible to have peaks or dips in the backscattering direction. Apart from the fact that only dips (no peaks) are present in the experimental data, the numerical calculations presented in Ref. 4 are in qualitative and quantitative agreement with the results reported by O'Donnell *et al.* (Opt. Lett. **21**, 1738 (1996)) for second harmonic generation in scattering from weakly rough metal surfaces.

The fact that dips rather than peaks were observed in the backscattering direction yields important information about the phenomenological constants that describe the nonlinear interactions at the metal surface, which helps deciding among different models for the nonlinear polarization of the metal[5].

More recently, O'Donnell and Torre (Opt. Commun. **138**, 341 (1997)) have reported measurements of the incoherently scattered second harmonic light from a strongly rough metal surface. Again, dips were observed in the backscattering direction and a possible explanation for them was proposed. For surfaces as rough as the ones studied in these experiments, the scattering problem cannot be treated by means of perturbation theory, and the multiple-scattering processes that give rise to the backscattering effects in the angular distribution of the mean intensity of the second harmonic light are of a different nature from those occurring in scattering from weakly rough surfaces. In subsequent numerical simulation studies of the generation and scattering of second harmonic light at randomly rough surfaces with relatively large roughness and slopes, it was found that the angular distribution of the scattered light at the harmonic frequency displays well-defined minima in the backscattering direction[6]. By the use of an iterative procedure for solving the scattering equations, it was shown that the observed features are due to destructive interference between waves that have been multiply scattered in the valleys of the surface. The qualitative and quantitative agreement between the calculated results and the experimental results of O'Donnell and Torre is very good.

4. Random Waveguides

Guided modes in a multi-mode, plane parallel waveguide, one of whose walls is a one-dimensional randomly rough surface over a length L, while the remaining walls is planar, can propagate ballistically, diffusively, or can be localized depending on the length L and on

the mode number of the mode. However, it has been shown[7,8] that modes characterized by all three transport properties can coexist within the same region of the surface disordered waveguide. This was done by calculating numerically the elements of the matrix of transmission amplitudes t_{nm} of an N-mode waveguide of the kind described above, where n labels the incoming channels while m labels the outgoing channels, as functions of L. The invariant embedding equations for the matrices of the reflection and transmission amplitudes were solved by a 6^{th} order Runge-Kutta method for each of N_p realizations of the surface profile function of the randomly rough wall, and functions $T_{nm} = |t_{nm}|^2$, $T_n = \sum_m T_{nm}$, and $g = \sum_n T_n$ were averaged over the results obtained from these realizations. It was found for the roughness assumed that in an 8-mode waveguide $\langle T_{11} \rangle$ decreased linearly with increasing L, signifying the quasiballistic transport of the (11)-transmission channel throughout the entire waveguide $L = 1500\lambda$ where λ is the wavelength of the wave entering the waveguide; $\langle T_{55} \rangle$ was found to follow the hyperbolic law $\langle T_{nn} \rangle = \ell_{nn}/L$, characteristic of diffusive transport of the (55)-transmission channel for $L \gtrsim 3.50\lambda$; while $\langle \ell n T_{88} \rangle$ was found to display the behavior $\langle \ell n T_{nn} \rangle = -L/\ell_{nn}^N$ for $L \gtrsim$, characteristic of Anderson localization. The localization length ℓ_{88}^L was found to be 1007λ. Thus, these results demonstrated the coexistence of quasiballistic, diffusive, and localized transport for different incoming channels within the same region of the surface disordered waveguide ($500 \lesssim L/\lambda \lesssim 1500$). Experimental conditions under which this coexistence could be observed were discussed as well.

5. Small-Contrast Perturbation Theory

For a random surface defined by the equation $x_3 = ((\zeta(x_1, x_2)$ small-amplitude perturbation theory, namely the expansion of the intensity of the scattered light in powers of $\zeta(x_1, x_2)$ is valid when the conditions $\delta/\lambda \ll 1$ and $\delta/a \ll 1$ are satisfied, where δ is the rms height of the surface, λ is the wavelength of the incident light, and a is the transverse correlation length of the surface roughness. However, these are not the only small parameters possible in a rough surface scattering problem. If the dielectric contrast between the medium of incidence and the scattering medium is small, then the scattered intensity can be calculated as an expansion in powers of the dielectric contrast in which each term contains all orders of the surface profile function $\zeta(x_1, x_2)$. Exactly this situation occurs in the scattering of x-rays from a randomly rough surface. The dielectric function of a metal in the range of frequencies is $\epsilon(\omega) = 1 - \eta(\omega)$, where the dielectric contrast $\eta(\omega)$ lies in the range from 10^{-6} to 10^{-3}. A theory of the coherent and incoherent scattering of x-rays from a randomly rough metal surface has been formulated[9], in which the mean differential reflection coefficient is expanded in powers of $\eta(\omega)$ through terms of second order. The results of these calculations are free from some of the limitations of earlier calculations of this quantity that were based on the Born or distorted wave Born approximations. It is suggested that this approach may be useful in theoretical studies of the scattering of electromagnetic waves from randomly rough dielectric-dielectric interfaces with a small dielectric constant.

6. Stokes Matrix in Conical Scattering from a One-Dimensional Random Surface

In the majority of the existing theoretical and experimental studies of the scattering of light from a one-dimensional randomly rough surface the plane of incidence has been assumed to be normal to the generators of the surface (in-plane scattering). In this geometry the plane of scattering coincides with the plane of incidence, and there is no cross-polarized scattering. For this choice for the plane of incidence most theoretical and experimental studies of the scattering of light from such surfaces were devoted to the cases where the incident light was p- or s-polarized. In contrast, in recent work O'Donnell and his colleagues (T. R. Michel, M. E. Knotts, and K. A. O'Donnell, J. Opt. Soc. Am. A**9**, 585 (1992)) assumed other polarization states of the incident and scattered light, and calculated and measured the elements of the Stokes matrix that give complete information about the scattering properties of one-dimensional randomly rough surfaces when the plane of incidence is normal to the generators of the surface. However, the most complete information about the scattering properties of such surfaces is obtained when the plane of incidence is not perpendicular to the generators of the surface. In this case the diffuse scattering of electromagnetic waves that occurs is called conical scattering, because the scattered radiation appears on the surface of a cone, rather than in a plane, due to the translational invariance of the scattering surface parallel to its generators. Although there have been experimental (R. E. Luna and E. R. Méndez, Optics Lett. **20**, 657 (1995); R. E. Luna, Optics Lett. **21**, 1418 (1996)) and theoretical (R. A. Depine, J. Opt. Soc. Am. A**10**, 920 (1993); L. Li, C. H. Chang, and L. Tsang, Radio Sci. **29**, 587 (1994)) studies of conical scattering, the elements of the corresponding Stokes matrix have neither been calculated nor measured until now. Therefore, in recent work[(10)] the elements of the Stokes matrix have been calculated by a computer simulation approach for the case of the conical scattering of light from a one-dimensional random metal surface. All 16 elements are found to be nonzero in this case.

In a subsequent work[(11)], for completeness the elements of the Stokes matrix were calculated by a computer simulation approach for the case of the conical scattering of light from a one-dimensional random perfectly conducting surface. It was found in this case that only four unique elements of the Stokes matrix are nonzero, as in the case of in-plane scattering. Moreover, these nonzero elements in the conical scattering of light of wavelength λ can be obtained from the corresponding elements in the in-plane scattering of light of an effective wavelength $\lambda_\ell = \lambda/\cos\phi_0$, where ϕ_0 is the conical angle. (When the mean scattering surface is the x_1x_2-plane, and the x_3-axis is directed into vacuum, namely the medium of incidence, ϕ_0 is the angle between the wavevector of the incident light and its projection on the x_2x_3-plane).

The results in these two papers enable complete information about the incoherent (diffuse) scattering properties of one-dimensional random surfaces to be obtained. It is hoped that they will stimulate experimental efforts to measure the elements of the Stokes matrix in conical scattering.

7. Scattering of Surface Plasmon Polaritons from Surface Defects

In recent experiments, the scattering of a surface electromagnetic wave – a surface plasmon polariton – from a surface defect was investigated (I. I. Smolyaninov *et al.*, Phys. Rev. Lett. **77**, 3877 (1996)). The authors of that work remarked that there was no theory of the scattering of a surface plasmon polariton from a single point defect on an otherwise planar metal surface. In response a nonperturbative theory of this scattering process, based on the method of reduced Rayleigh equations, was constructed[12]. It was assumed that the defect possess circular symmetry. Specifically, the surface was defined by the equation $x_3 = A\exp[-(x_1^2+x_2^2)/R^2]$. The surface defect described by this equation was a protuberance for $A > 0$; it was an indentation for $A < 0$. One-dimensional integral equations for the amplitudes corresponding to different rotational "quantum" numbers m were derived and solved numerically. The results were used to calculate the differential cross sections for the scattering of an incident surface plasmon polariton into volume electromagnetic waves in the vacuum above the metal, and into other surface waves, and the intensity of the electromagnetic field near the surface. In addition, the resonant scattering of the surface plasmon polariton due to the surface shape resonances supported by the surface defect was also investigated. The results obtained showed good agreement with the experimental results of Smolyaninov *et al.*

In two subsequent papers[13,14] the one-dimensional analogue of this problem, namely the scattering of a surface plasmon polariton of frequency ω incident normally on a surface defect on an otherwise planar metal surface, defined by the equation $x_3 = \zeta(x_1)$, was studied on the basis of the corresponding reduced Rayleigh equation. This equation was solved by two approaches. In the first, the scattered field was calculated as an expansion in powers of the surface profile function $\zeta(x_1)$, and terms of zero and first order were retained. From the result the intensity of the total magnetic field in the vacuum $I(x_1, x_3|\omega)$ was calculated to first order in $\zeta(x_1)$ as a function of x_1 for a constant value of x_3 well within a wavelength from the surface. The result had the form

$$I(x_1, x_3|\omega) = I_0(x_1, x_3|\omega) + e^{-k_2(\omega)x_1} \int_{-\infty}^{\infty} du\eta(x_1 - u)F(u, x_3) \tag{1}$$

where $k_2(\omega)$ is the imaginary part of the wave number of the incident surface plasmon polariton, and $\eta(x_1) = \zeta(x_1)e^{-k_2(\omega)x_1)}$. The functions $I_0(x_1, x_3|\omega)$ and $F(u, x_3)$ are known functions. Equation (A.1) can be regarded as an integral equation of convolution form for the surface profile function, whose solution by Fourier methods is

$$\zeta(x_1) = e^{k_2(\omega)x_1} \int_{-\infty}^{\infty} \frac{dp}{2\pi} e^{ipx_1} \frac{\Delta\hat{I}(p, x_3|\omega)}{\hat{F}(p, x_3)} \tag{2}$$

where

$$\begin{aligned} \Delta\hat{I}(p, x_3|\omega) &= \int_{-\infty}^{\infty} dx_1 e^{ipx_1} e^{i_2(\omega)x_1}[I(x_1, x_3|\omega) - I_0(x_1, x_3|\omega)] && (3) \\ \hat{F}(p, x_3) &= \int_{-\infty}^{\infty} dx_1 e^{-ipx_1} F(x_1, x_3). && (4) \end{aligned}$$

The reduced Rayleigh equation was then solved exactly by a numerical approach, and the result was used to calculate the intensity of the total magnetic field in the vacuum $I(x_1, x_3|\omega)$. This result for $I(x_1, x_3|\omega)$ was used as "experimental" data in determining $\zeta(x_1)$ by means of Eq. (A.2). The reconstruction of the surface profile function by this approach was very good, and surface structures with lateral dimensions of the order of one-tenth the wavelength of the incident surface plasmon polariton were resolved in this manner[13]. In addition, a ten wavelength segment of a random surface was also well reconstructed by this approach[14].

In order for surface polariton scattering by surface defects to be the basis for a near-field scanning optical microscope the perturbing effects of the probe used for measuring $I(x_1, x_3|\omega)$ have to be incorporated into the scattering theory underlying it. That is a goal for the future.

8. Inverse problems

The majority of the theoretical and experimental studies of the scattering of light from randomly rough surfaces carried out to date have addressed the so-called direct problems. This is the determination of the contributions to the mean differential reflection coefficient (mdrc) from the coherent (specular) and incoherent (diffuse) components of the light scattered from a surface whose statistical properties, such as the rms height and the power spectrum of the roughness, are known. The inverse problem, that of determining the surface profile or the statistical properties of the surface from scattering data, is a much more difficult problem, and has not been addressed to the same extent in the literature. In a recent paper[15] the reverse Monte Carlo method has been used to determine the power spectrum of a one-dimensional randomly rough metal surface from experimental data for the contribution to the mdrc from the incoherent component of the scattered light obtained by C. S. West and K. A. O'Donnell at two different wavelengths of the incident light (J. Opt. Soc. Am **A12**, 390 (1995)). In this approach (R. L. McGreevy and M. A. Howe, Ann. Rev. Mat. Sci. **22**, 217 (1992)) an initial guess $g_0(|k|)$ is made for the power spectrum of the surface roughness, and the contribution to the mdrc from the incoherent component of the scattered light is computed. The squared modulus of the difference between this result and the experimental result is then integrated over all scattering angles, with a weighting function that is inversely proportional to the variance of the experimental data about their mean, to yield a number χ_0. The power spectrum is then subjected to a random change to produce a new power spectrum $g_0(|k|)$, and this procedure is repeated. If the value of the resulting integral χ_1 is smaller than χ_0, then $g_1(|k|)$ is retained over $g_0(|k|)$ as a good guess for the power spectrum. If $\chi_1 \geq \chi_0$ then $g_1(|k|)$ is retained over $g_0(|k|)$ with probability $p = \exp(\chi_0 - \chi_1)$. Otherwise, $g_0(|k|)$ is retained. This procedure is repeated until the $(\text{mdrc})_{\text{theory}}$ agrees with $(\text{mdrc})_{\text{expt}}$ by an amount that is smaller than the experimental error in the mdrc. The resulting final guess for the power spectrum is taken as the representation of the true spectrum. The quality of the determination of the power spectrum by this approach is very good.

9. Electromagnetic Surface Shape Resonances

Surface shape resonances are excitations that are associated with an isolated defect on an otherwise planar surface. They are characterized by discrete, complex frequencies that depend on the shape of the surface perturbation. Electrostatic and electromagnetic surface shape resonances associated with a local perturbation on the surface of a metal or perfect conductor have attracted a great deal of attention because they are believed to play an important role in surface enhanced Raman scattering and in the enhancement of second harmonic generation in reflection from a rough metal surface. However, until now no direct experimental evidence for the existence of electromagnetic surface shape resonances has been provided. In a recent study (A. Zuniga-Segundo and O. Mata-Mendez, Phys. Rev. **B46**, 536 (1992)) of the scattering of a beam of s-polarized light from a rectangular groove on an otherwise planar surface of a perfect conductor the intensity of the scattered light as a function of its frequency, for fixed angles of incidence and scattering, showed well-defined dips at frequencies attributed by the authors to those of surface shape resonances, although in fact no independent calculation of those frequencies was carried out by them. The angular dependence of the intensity of the scattered light was also found to undergo a significant rearrangement when the frequency of the incident light at a fixed angle of incidence was tuned to the vicinity of these particular frequencies. However, in more recent calculations[16] the frequencies of the electromagnetic surface shape resonances of both p- and s-polarization associated with a rectangular groove on the otherwise planar surface of a perfect conductor, and the scattering of a Gaussian beam of p- and s-polarized light from the same groove, were calculated by both a modal approach and a numerical method based on Green's second integral identity in the plane. It was shown that the dips in the frequency dependence of the intensity of the scattered light in s-polarization for fixed angles of incidence and scattering found by Zuniga-Segundo and Mata-Mendez, and which were found in Ref. 16 to occur in the scattering of p-polarized light as well, do not occur at the frequencies of the surface shape resonances as asserted by these authors. Instead, it was shown that they occur at frequencies at which the total electric field (s-polarization) or the normal derivative of the total magnetic field (p-polarization) nearly vanish across the throat of the groove. In these cases, the surface, including the groove, acts as a mirror. As a result, there is strong scattering into the specular direction, and the intensity of scattering into other angles is therefore strongly suppressed. In addition, it was shown that while the dips in the frequency dependence of the intensity of the scattered light associated with the s-polarized surface shape resonances are masked by the dips found by Zuniga-Segundo and Mata-Mendez, this is not the case for dips associated with the p-polarized surface shape resonances. The latter should therefore be observable in experimental studies of the scattering of p-polarized light from a rectangular groove on an otherwise planar surface of a highly conducting metal.

10. New Features in Speckle Correlations of Light Scattered from Volume Disordered Dielectric Media

The speckle correlations in the light scattered from a volume disordered dielectric medium were studied theoretically on the basis of a scalar wave treatment[17,18]. What was calculated was the angular intensity correlation function $C(\vec{q}, \vec{k}|\vec{q}', \vec{k}') = \langle \delta I(\vec{q}|\vec{k}) \delta I(\vec{q}'|\vec{k}')\rangle$, where $\delta I(\vec{q}|\vec{k}) = I(\vec{q}|\vec{k}) - \langle I(\vec{q}|\vec{k})\rangle$, and the intensity $I(\vec{q}|\vec{k})$ is proportional to the differential scattering coefficient for the scattering of light whose wavevector is $\vec{k}$ into light whose wavevector is $\vec{q}$. Results were obtained for three contributions to $C(\vec{q}, \vec{k}|\vec{q}', \vec{k}')$, namely the $C^{(1)}, C^{(10)}$, and $C^{(1.5)}$ contributions, which arise from three distinct classes of diagrams in the diagrammatic perturbation calculation of $C(\vec{q}, \vec{k}|\vec{q}', \vec{k}')$. The contribution $C^{(1)}$ is proportional to $\delta(\vec{q} - \vec{k} - \vec{q}' + \vec{k}')$ and contains the memory and reciprocal memory effects. It has been studied in earlier theoretical and experimental investigations of $C(\vec{q}, \vec{k}|\vec{q}', \vec{k}')$. $C^{(10)}$ is a new contribution to $C(\vec{q}, \vec{k}|\vec{q}', \vec{k}')$ that is of the same order of magnitude as $C^{(1)}$, and is proportional to $\delta(\vec{q} - \vec{k} + \vec{q}' - \vec{k}')$. $C^{(1.5)}$ is also a new contribution to $C(\vec{q}, \vec{k}|\vec{q}', \vec{k}')$. It possesses an unrestricted dependence on the four wave vectors, $\vec{q}, \vec{k}, \vec{q}', \vec{k}'$, and displays a series of interesting peaks related to the resonant scattering of light by volume disorder. The new contributions $C^{(10)}$ and $C^{(1.5)}$ had been studied earlier in the scattering of light from randomly rough surfaces (V. Malyshkin *et al.*, Opt. Lett. **22**, 946 (1997)), but this is the first time they have been investigated in the scattering of light from volume disordered media.

11. Scattering of Electromagnetic Waves from a One-Dimensional Random Metal Surface with a Localized Defect

Two experimental investigations have been carried out of the angular intensity correlation function of the light scattered when a polarized beam of light is incident from vacuum on a one-dimensional rough surface[19,20]. One part of the surface used consisted of a dielectric film (photoresist) deposited on a glass substrate, while the other part was identical to the first except for the presence of a localized defect on it, a Gaussian ridge. The rms height of the random surface was approximately 0.37 μm, and its transverse correlation length was 2.5 μm. The ridge was defined by the profile function $P\exp(-x_1^2/b^2)$, where $P \simeq 1.0\mu$m and $b = 3.2\mu$m. The correlation function of the intensity of the light scattered from the surface should display a strong correlation when the condition

$$\sin\theta_s - \sin\theta_0 = \sin\theta_s' - \sin\theta_0' \tag{5}$$

is satisfied. This is the condition for the occurrence of the memory and reciprocal memory effects. In the experiment θ_0 was kept fixed and equal to θ_0', while the correlation function was measured as a function of $\Delta\theta_s = \theta_s - \theta_s'$ for a fixed value of θ_s'. The peak in the correlation function at $\Delta\theta_s = 0$ decreased more slowly with increasing $\Delta\theta_s$ for the random surface with a defect than for the random surface without a defect, demonstrating the sensitivity of the angular intensity correlation function to the presence of the defect.

Papers published with support from Army Research Office Grant DAAH 04-96-1-0187

1. T. A. Leskova, A. A. Maradudin, A. V. Shchegrov, and E. R. Méndez, "Spectral Changes of Light Scattered from a Random Metal Surface in the Otto Attenuated Total Reflection Configuration," SPIE **3426**, 14-31 (1998).

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